Carrier Plus: A Sensor Payload for Living With a Star Space Environment Testbed (LWS/SET)

Breakout Session Summary

Why a SET Sensor Payload?

- **UV/Visible focal plane array (FPA) technologies are identified as critical to the NASA mission yet they are inherently sensitive to radiation**
  - Source: NASA Office of Space Science roadmapping effort
- **Technologies discussed included: Charge coupled devices (CCDs), active pixel sensors (APS), p-CCDs, Si CMOS hybrids, charge injection devices (CIDs), etc.**
  - CCDs have highest performance because they have the highest performance
    - **Improved performance is in work for p-CCDs, APS, and Si CMOS hybrids due to their benefits concerning radiation tolerance**
- **Sensors are highly susceptible to displacement damage effects**
  - Protons & secondaries generated by proton interactions with nearby shielding, etc., create lattice defects in the silicon that increase the dark current, reduce charge transfer efficiency (for CCDs) and produce hot pixels
  - Beyond Carrier Plus: Infrared sensors and broader wavelength sensor coverage called out in 2001 Pre-NRA Workshop still applicable.
- **Investigations require exposure to solar-variant environment**
  - Solar events can drive the total ionizing dose, displacement damage and single event transient effects of a sensor

Carrier Plus: A Partnered Program

- **DTRA is our sensor partner.**
  - Will identify 2 of the 4-6 sensors flown on the 1st Carrier Plus flight
- **The remaining sensor experiments will be competed using the NRA process.**

Prioritized Findings

- **Correlative environment monitors are especially critical for focal plane arrays (FPAs).**
  – DMSP environment (or any orbit with exposure to the belts and solar flare activity) is ideal for sensor studies
- **Telemetry constraints require significant accommodation in order to yield useful data.**
- **In order to accommodate a wide range of frame rate/resolution requirements, experimenters must be responsible for critical FPA circuitry.**
- **Measurement suite**
  – FPA cooling to at least –80°C required for relevant applications.
- **Sensor assemblies with flat field illumination:**
  – "Mechanical Interface Control Document" also critical.
  – Qualification issues for sensor subassemblies.

Validation of Sensor Performance Predictions

- **Unlike most microelectronic devices, sensors are highly susceptible to displacement damage effects**
  - Protons and secondaries create lattice defects that increase the dark current, reduce charge transfer efficiency (CTE), and produce hot pixels
    - **Secondaries are produced in the heavy shielding often required for sensor survivability on-orbit**
- **Models used to predict displacement damage effects have not been validated by careful comparison with on-orbit performance**
- **Hence large radiation design margins (RDM) are used for a soft technology**
- **Carrier Plus is expected to reduce the RDMs thereby allowing sensor operation in a scientifically more useful orbit or for a longer mission.**

Validation of Sensor Performance Predictions

- **On–orbit measurements will correspond with ground testing.**
  - Experimenters will be provided with focal plane electronics support board to facilitate testing and lower program risk.
- **On-orbit dosimetry is critical for calibration with predicted environment.**
  - We do not know the Non-ionizing energy loss function as well as we know the linear energy transfer (LET) used to characterize total integrated dose (TID) effects.
  - Transient and displacement damage modeling issues need to be coordinated with experimenters (e.g. REACT for transients)
  - Multi-channel proton spectrometer is essential.
    - **Light Particle Detector (LPD) has been proposed.**
      - Do we need measurements behind shielding?
    - **Must translate environment to charge coupled detector (CCD) locale.**
- **Vanilla n-CCDs are the best characterized focal plane arrays, and are ideal for model validation**

The Telemetry Issue

- **Ideally we would have raw frames provided for mid-size focal plane arrays (FPAs).**
  - Even ~2 kbps with reasonable data storage alleviates the log jam.
- **At the 1 kbps level, we must identify events of interest and pass down relevant sub-frames**
  - Requires thorough ground testing of algorithms.
  - Requires the ability to adjust algorithms on-orbit via look up tables.
  - Requires significant onboard processing capability.
  - Must prioritize measurements.
    - **In the event of a flare, transient measurements take precedence, and we operate 1 FPA at a time.**

The Frame Rate/Resolution Issue

- **An astronomer may integrate for 1.5 hours and care about relatively few electrons noise, whereas DoD may want a 20 Megapixels per second readout but can tolerate higher noise levels.**
  - To accommodate both groups and dynamic range requirements, we need to have the analog drive for the focal plane array, immediate output processing (e.g. correlated double sampling for a charge coupled detector, and analog-to-digital converter (ADC) function on the experimenter's card).
    - **Perhaps the increased burden on the experimenter and program risk can be alleviated with bulk buys for some key parts by the project (e.g. TEC, ADCs).**
    - **Support from flight hardware engineering services may be key.**

Required Measurement Suite

- **Dark Current (temperature dependent measurements between -80 to +40 +/- 0.1°C):**
  - Average dark current
  - Serial subframes capturing pixel by pixel dark currents (-80 °C needed to simulate some applications and to study "hot pixels")
- **Serial subframes (or infrequent frames) capturing proton and heavy ion transients**
- **Charge Coupled Detectors:**
  - Charge transfer efficiency measurements (temperature dependent measurements between -80 to +40 +/- 0.1°C):
    - **Extended pixel edge response, first pixel response, Cosmic Ray tails, pinhole**
- **Photometrics (Multiple wavelengths)**
- **Photon transfer curve**
- **LU detection & reset**
- **Correlative Environment Measurements:**
  - Total integrated dose dosimeter
  - Proton Spectrometer (displacement damage effects): 4-6 channels between ~1 MeV and >~200 MeV

Sensor Assemblies

- **Sensor assemblies need to have a provision for flat field illumination:**
  - GSFC provides the optical subassembly and the electronics support board, whereas the experimenter provides the focal plane array daughter board
    - **“Mechanical Interface Control Document” is critical as all must plug and play**
  - Requires close interaction between Carrier-Plus and experimenters.
    - **Critical Design Review at experimenter’s location?**
  - Qualification issues for sensor assemblies.
    - **Daughter board need shake, rattle and roll but so does the assembly.**

Technology Requirements List from Breakout Session: All Requirements Have Equal and High Priority

1. Active Pixel Sensors
2. CMOS Hybrid Focal Plane Array
3. Infrared Focal Plane Arrays
4. n-Channel Charge Coupled Detectors
5. p-Channel Charge Coupled Detectors

Technology #1: Active Pixel Sensors

- Background: Recent advances in radiation tolerant CMOS technology applied to monolithic active pixel sensors makes this technology attractive for space sensor and imaging applications, especially since CMOS should not be as susceptible to displacement damage like CCDs. These focal planes have not been evaluated for transient response, total dose, and other radiation effects in space.
  –
- Technology Requirement: Focal plane arrays have been observed to respond to natural radiation in space in modes that were not predicted adequately by ground testing (e.g. at accelerators). Full characterization of radiation response, both transient and cumulative, is needed to reduce margin requirements to acceptable levels in order to apply this technology to science missions.
- Correlative environment measurement requirements: protons and electrons (rate and cummulative)
  –
- Environments of interest: Polar preferred but not essential; > 800km altitude; > 70 degrees preferred (SAA desired)
- Telemetry requirement: up to 100 megabits/sec reported to the carrier plus (reduced to 100 bps final telemetry rate)

Technology #2: CMOS Hybrid Focal Plane Array

- **Background: Recent advances in radiation tolerant CMOS technology applied to hybrid sensors makes this technology attractive for space sensor and imaging applications, especially since CMOS should not be as susceptible to displacement damage like CCDs.**
- **Issue: Focal plane arrays respond to natural radiation in space in modes that were not predicted adequately by ground testing (e.g. at accelerators).**
  - These focal planes have not been evaluated for transient response, total dose, and other radiation effects in space.
  - Full characterization of radiation response, both transient and cumulative, is needed to reduce margin requirements to acceptable levels in order to apply this technology to science missions.
- **Correlative environment measurement requirements:**
  - Protons and electrons (rate and cummulative)
- **Environments of interest:**
  - Polar environment preferred but not essential; > 800 km altitude; >70 degrees preferred (South Atlantic Anomaly desired)
- **Telemetry requirement: Up to 100 megabits/sec reported to the carrier plus (reduced to 100 bps final telemetry rate)**

Technology #3: Infrared (IR) Focal Plane Arrays (FPA)

- **Background: Many of NASA's, DoD's and DoE's future missions target the infrared wavelengths. Little is known about the behavior of HgCdTe, InSb, etc. FPAs in a radiation environment.**
- **Issue: The understanding of and the ability to predict how IR FPAs will perform in a radiation environment is needed to help reduce the margin requirements to more manageable levels in science missions.**
- **Correlative environment measurement requirements:**
  - Protons and electrons (rate and cumulative)
- **Environments of interest:**
  - GTO or high inclination LEO > 800 km

Technology #4: n-Channel Charge Coupled Detectors (CCDs)

- **Background: n-channel CCDs are one of the most studied and mature sensors. Over the years, dozens of models have been created to predict how these devices would respond to radiation damage but none have been validated with data from space.**
- **Issue: Missions that use n-channel CCDs use large margins to account for uncertainties in their predicted performance in the radiation environment in space.**
  - It is important to validate these models verified by flying a plain, vanilla, n-channel CCD with associated on-board dosimeters.
  - The understanding of and the ability to predict how CCDs will perform in a radiation environment will help reduce the margin requirements to more manageable levels in science missions.
- **Correlative environment measurement requirements:**
  - Protons and total integrated dose
- **Environments of interest: GTO, HEO, or high inclination LEO > 800 km**
- **Other Requirements: Continuous - 80 degrees C with periodic warmups for hot pixel annealing**

Technology #5
p-Channel Charge Coupled Detectors (CCDs)

- **Background: p-channel CCDs are predicted to be at least one order of magnitude less sensitive to displacement damage than n-channel CCDs, but these focal planes have not been evaluated for transient response, total dose, and other radiation effects in space.**
  - n-channel CCDs are susceptible to displacement damage from protons in the space environment.
- **Issue: CCD focal plane arrays have been observed to respond to natural radiation in space in modes that were not predicted adequately by ground testing (e.g. at accelerators).**
  - Full characterization of radiation response, both transient and cumulative, is needed to reduce margin requirements to acceptable levels in order to apply this technology to science missions.
- **Correlative environment measurement requirements:**
  - Protons and electrons (rate and cumulative)
- **Environments of interest: High inclination LEO > 800 km preferred but not essential; South Atlantic Anomaly desired.**
- **Other Requirements: Telemetry to 100 megabits/sec reported to the carrier plus (reduced to 100 bps final telemetry rate)**